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Lawrence Livermore National Laboratory

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SUMMARY

Obtaining detailed knowledge of the condition of the electron beam delivered to the experimental tank is of prime importance in the attempt to correlate the propagation data with theory. There are many interesting and unique features of the beam delivered by ATA to the experimental tank.

CO-PROPAGATING SECONDARY ELECTRONS FROM THE LASER-INDUCED ION CHANNEL

Perhaps the most interesting feature of the beam produced by ATA is the additional current produced by acceleration of the secondary electrons of the laser-produced ion channel. This additional current may amount to several kiloamperes. Essentially, the secondary electrons are swept up by the axial electric fields of the some 150 accelerating cavities present in the laser

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guiding region of ATA. This current is observed even when the injector is turned off. Its magnitude is a sensitive function of the relative timing between the laser pulse and the gap accelerating voltages. A resistive wall current monitor trace of this current is shown in Figure 1. A simulation of this process of current accumulation throughout ATA is discussed in the paper by John Boyd in this session.

The shape of the extra current is altered in the presence of the injected beam. In general, the additional current near the head of the pulse, which is referred to as the precursor, is maintained while the current later in time is reduced. The amount of reduction is also a sensitive function of the relative timing of the laser with respect to the accelerating voltages.

Since the extra current arises from gap interactions throughout the accelerator it is to be expected that the energy spectrum of the total beam will have a broad distribution. A measurement of the beam energy was performed by Ken Struve using the device shown in Figure 2. The beam at the end of the accelerator is guided up to a beam dump consisting of many carbon plates with .25" diameter holes in their centers. Any residual beam which passes through the dump enters the deflecting magnetic field of the energy analyzer. Those electrons with the proper energy will be turned a sufficient amount to pass through the sensitive wall current monitor at the top of the apparatus. In the only measurement performed some 2 kA of injected current and additional current were transported to the dump. If one compares the current passing through the dump with the <u>difference</u> between the trace at the output of the accelerator and that just upstream of the laser guiding zone it appears that the bulk of the current surviving the dump into the energy analyzer is just the "extra" current. The output of the energy analyzer and the current waveform through the dump are shown in Figures 3a and 3b respectively, while the difference between the upstream and downstream current signals are shown in Figures 4a and 4b respectively.

The inferred spectrum of the extra current, low energy toward the head of the pulse and higher energy toward the tail, is similar to that predicted by the DPC Code and will be discussed by John Boyd.

There is to date no clean measurement of the injected beam energy so that this parameter is known approximately only to within 25%.

VACUUM EXPANSION EXPERIMENTS INSIDE THE ACCELERATOR

The inference from the above discussion is that the precursor has a lower emittance than the injected beam and hence survives through the dump. A series of vacuum expansion measurements performed inside the accelerator transport section (upstream of the experimental tank) was performed which qualitatively supports this inference. A diagram of the experiment is shown in Figure 5. The electron beam is laser guided down to the end of the accelerator. A 1" diameter aperture followed by a vacuum pump is placed in the beam line just downstream of the accelerator in order to create a precipitous benzene pressure decrease down to a sufficiently low level that laser guiding would be inoperative. The resulting current as a function of axial distance down the transport tube was then measured both with the injector on and with the injector off. Overlays of the current recorded at two different locations is shown for the case of injector on in Figure 6 and injector off in Figure 7. There is virtually no current loss over the approximately 3 meters of separation between the monitors in the case with the injector off in contrast to the considerable loss evident in the body of the pulse with the injector on. Studies with the Wire Transport Code show that this is consistent with less than a factor of five normalized emittance growth for the main beam. A typical value for the r.m.s. normalized emittance of a 10 kA beam out of the injector is .25 radian-cm. During the course of the experiments there was occasionally a small amount of magnetic field threading the cathode. This field gave rise to an r.m.s. normalized canonical angular momentum of up to .2 radian-cm. The implication for the laser induced current is that its unnormalized emittance is less than roughly .01 radian-cm.

VACUUM EXPANSION EXPERIMENTS IN THE PROPAGATION TANK

Several series of vacuum expansion experiments were performed in the propagation tank in order to study the time varying emittance of the beam. The beam passes through a high pressure benzene/laser damping zone just upstream of the propagation tank. A schematic of the layout is shown in Figure 8. The damping zone is 4.5 meters in length and the upstream end is terminated by a 1 mm. thick graphite foil with a 5-7 mm. diameter aperture in it. The downstream end of the zone is terminated by a 200 mil thick (.2") graphite foil which separates the benzene zone from the propagation tank. The laser beam diameter just upstream of the zone is some 2-2.5 cm in diameter and the position of the laser jumps from shot to shot on the order of at least several millimeters. The 5-7 mm aperture defines a narrow and centered laser beam in the 4.5 meter zone which is then filled to a pressure of approximately

5 microns of benzene in order to provide a wire-like damping zone to reduce transverse beam motion.

The beam is strongly pinched inside the high pressure benzene zone. The time to fully neutralize an e-beam in benzene due to collisional ionization is 167/P ns, where P is the benzene pressure in microns. We therefore expect to see full neutralization of the beam by 33 ns.

Two effects will determine the expansion rate of the beam in the evacuated propagation tank. The first effect is the scattering due to the thick foil and the second is the pinch angle in the benzene zone due to the strong focusing of the nearly neutralized beam. As beam current increases the total thermal r.m.s. angle of the beam electrons leaving the foil should increase as the pinch angle in the benzene zone will increase with current. The final beam energy should also drop with current as the accelerating cells are loaded down by the beam with the consequence that the accelerating cell voltages decrease with current. These trends are clearly apparent in the data shown in Figure 9. Superimposed on the data points are simulation results from the particle code Beamfire which treats the transport through the benzene zone and foils into the vacuum expansion region. If one takes the highest γ measured by the energy analyzer at a current of 2 kA as characteristic of the injected beam and corrects for the loading of the cell voltages with current one obtains the points shown in Figure 10. There is excellent qualitative agreement but the inferred thermal angles are all too high. However, if one takes the unloaded energy of the machine to be 25% higher, the Beamfire results now line up quite nicely with the data.

If one computes I/I_A for the data using the values of γ which match the vacuum expansion, it is seen that the inferred thermal angles are all larger than I/I_A. This implies that the beam will violently expand when it enters high pressure gas as the thermal angles are higher than the equilibrium value. The implications of this for propagation will be discussed by others in this session.

GJC:emj

4397t

Filename: b:e12401.rev

File comment: laser current at 3.13 microsec no injector

Frame comment: 171 and 201.1

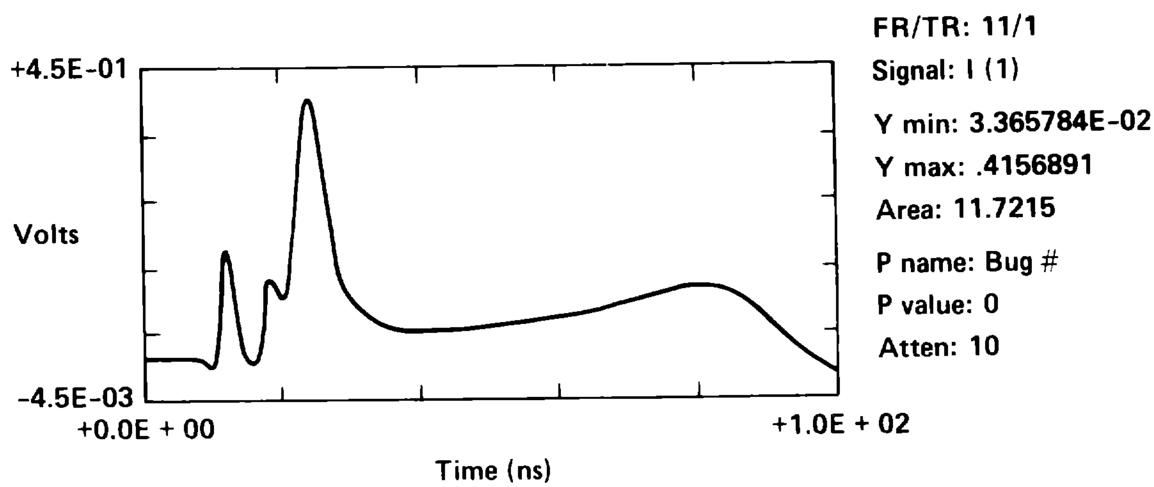


Figure 1

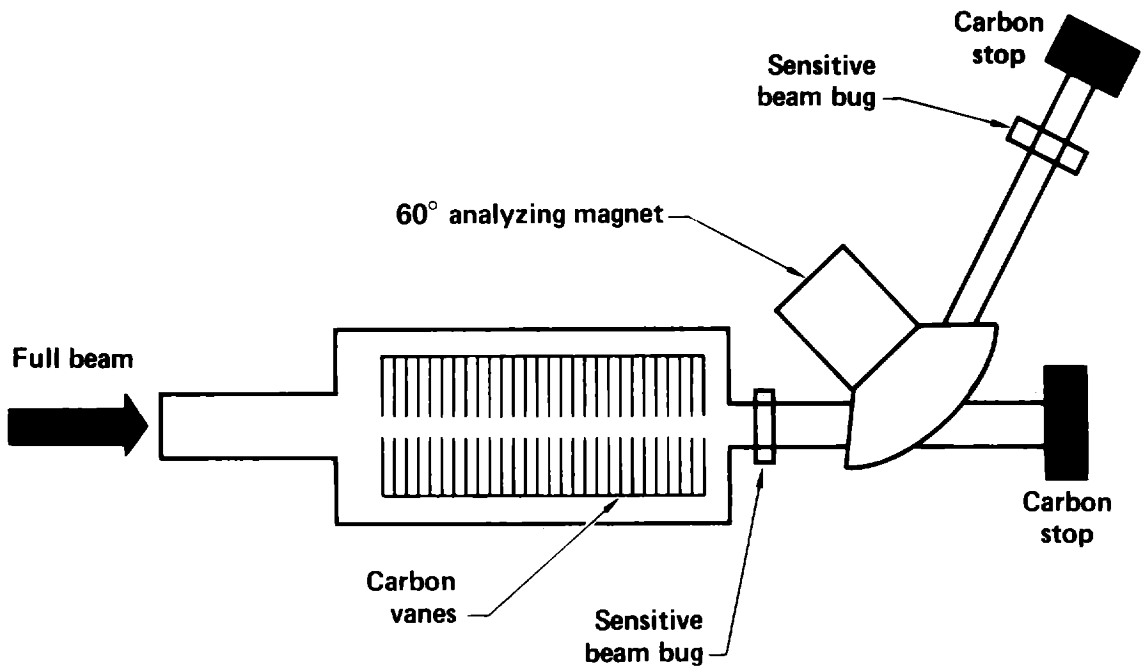

Carbon
stop
Sensitive
beam bug
60° analyzing magnet
Full beam
Carbon
stop
Carbon
vanes
Sensitive
beam bug

Figure 2

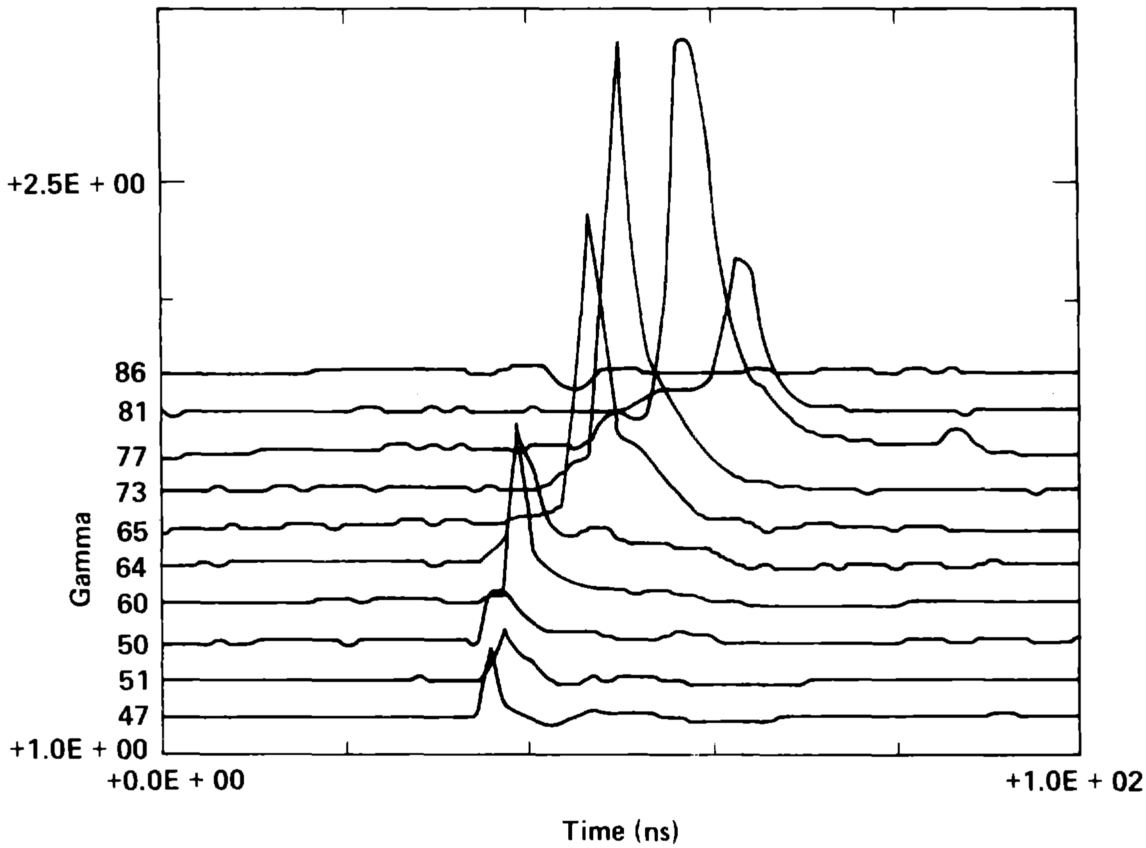

+2.5E + 00
86
81
77
73
65
64
60
50
51
47
+1.0E + 00
Gamma
+0.0E + 00
+1.0E + 02
Time (ns)

Figure 3a

Filename: d15005.rev   Date: 17-Jan-85

File comment: beam energy, 2 kA from the collimator

Frame comment: 1.4 kG, 324 amps

Overlay: SSB1
Overlay: 2/2
FR/TR: 14/2
Signal: SSB1
Y min: -.7729187
Y max: 3.008331
Area: -43.927
P name:
P value: 0
Atten: 1

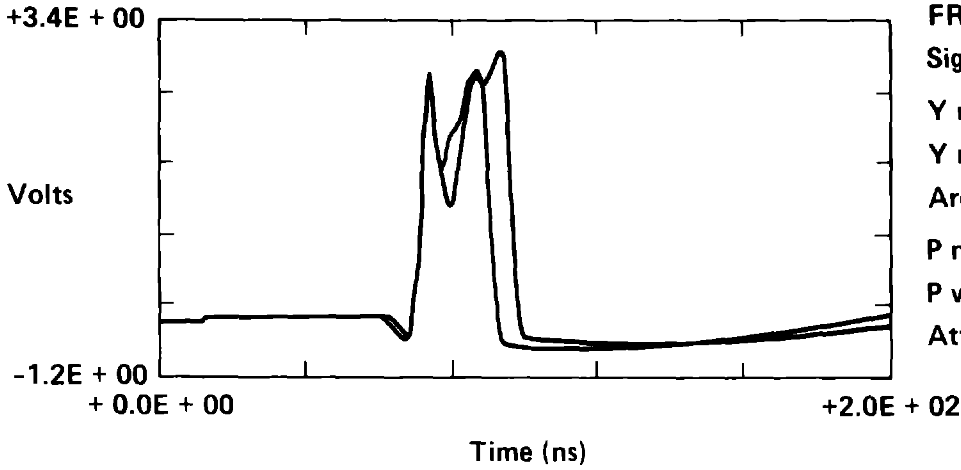


Figure 3b

Filename: a:d15002.ata
File comment: low current, 2kA
Frame comment: none

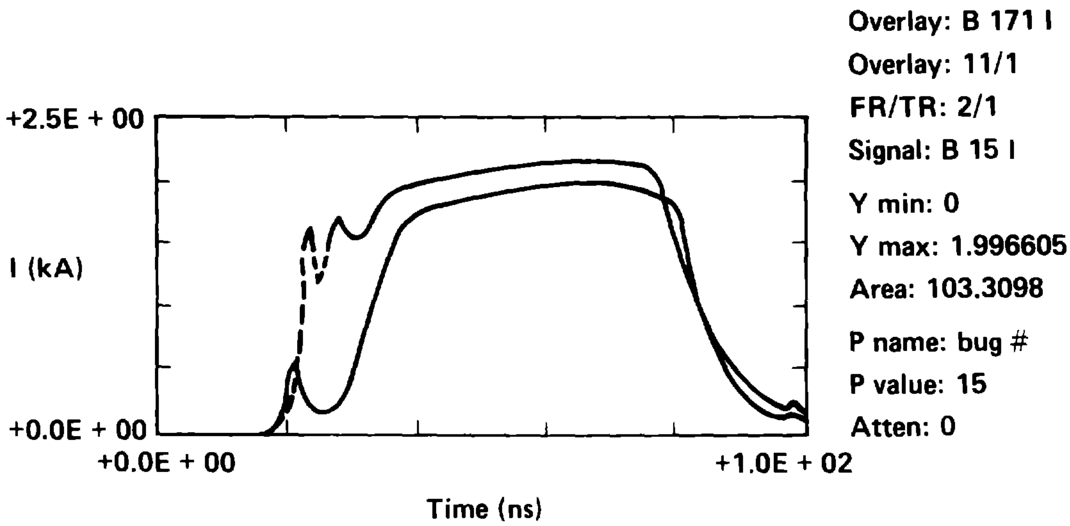


Figure 4a

Filename: a:d15002.ata

Date: 17-Jan-85

File comment: low current, 2kA

Frame comment: none

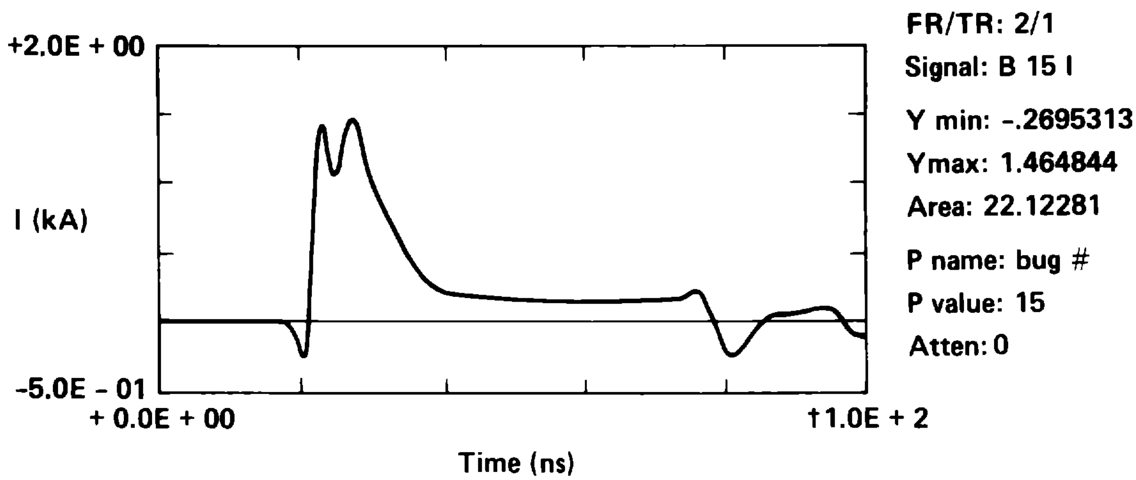


Figure 4b

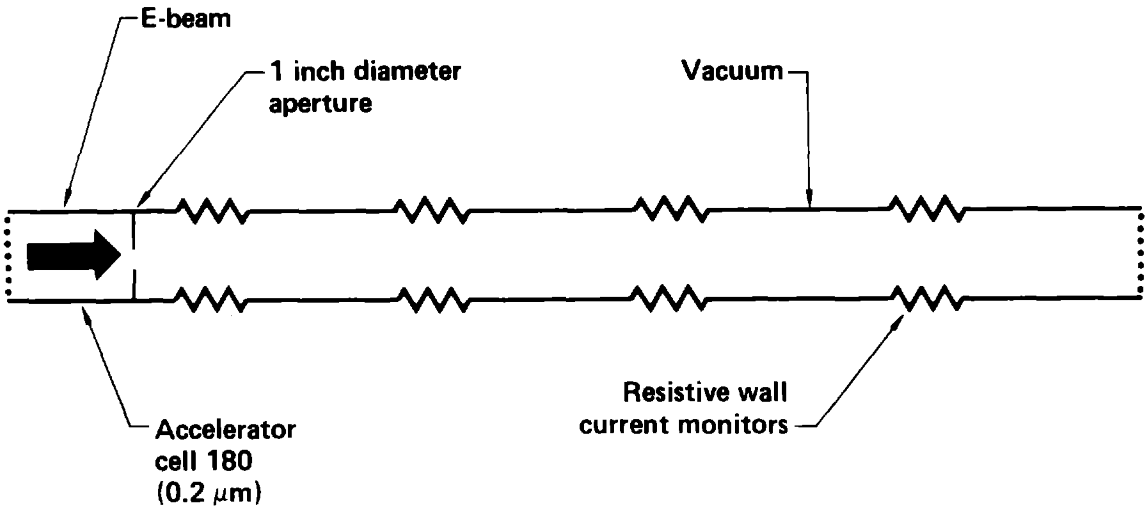

E-beam
1 inch diameter
aperture
Vacuum
Accelerator
cell 180
(0.2 μm)
Resistive wall
current monitors

Figure 5

Filename: b:e11902.rev Date: 11-Apr-85

File comment: 3.13 US no benzene

Frame comment: 1.1 and 4.72

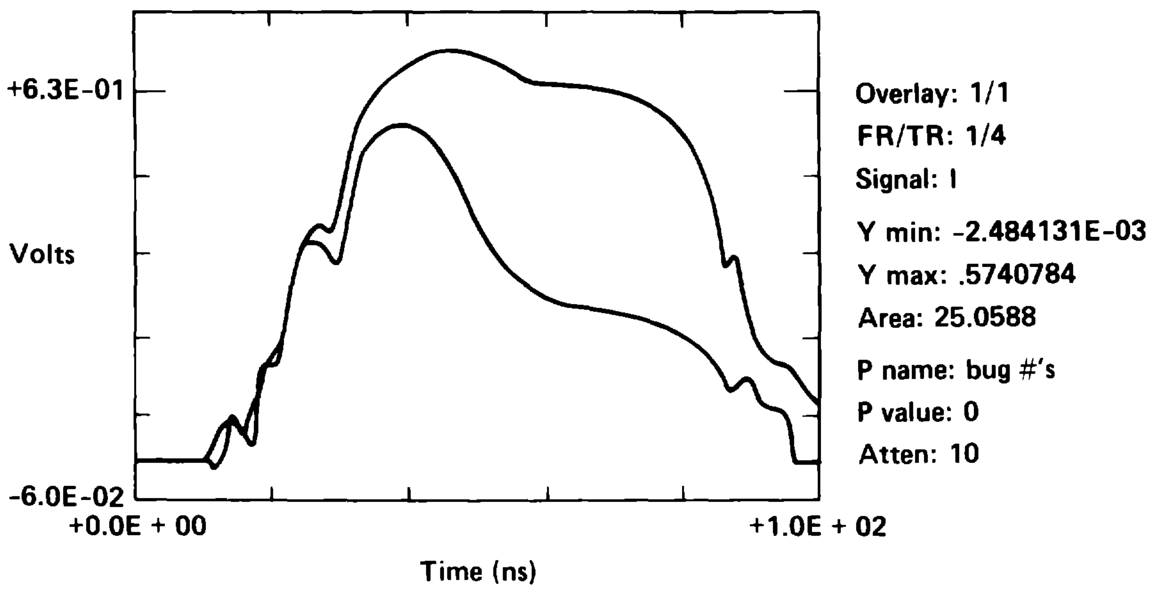


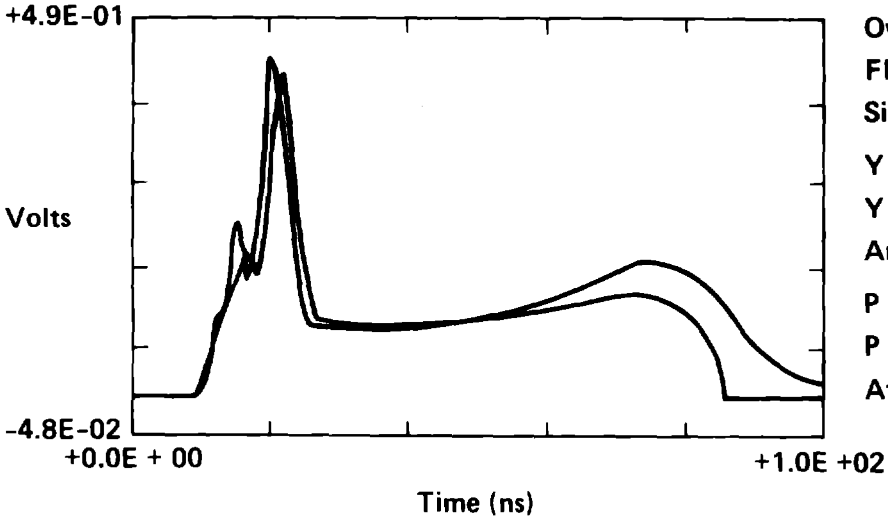
Figure 6

Filename: b:e11901.rev

Date: 11-Apr-85

File comment: 3.13 US no benzene no injector

Frame comment: 1.1 and 4.72



Overlay: 1/1

FR/TR: 1/4

Signal: I

Y min: -2.804566E-03

Y max: .4456329

Area: 9.175067

P name: bug #'s

P value: 0

Atten: 10

Figure 7

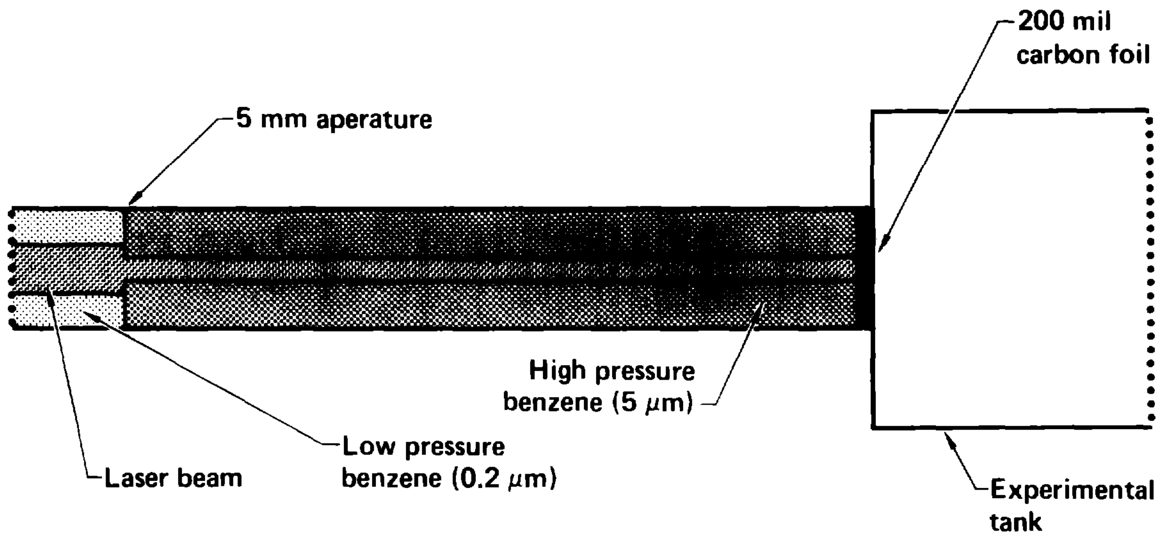
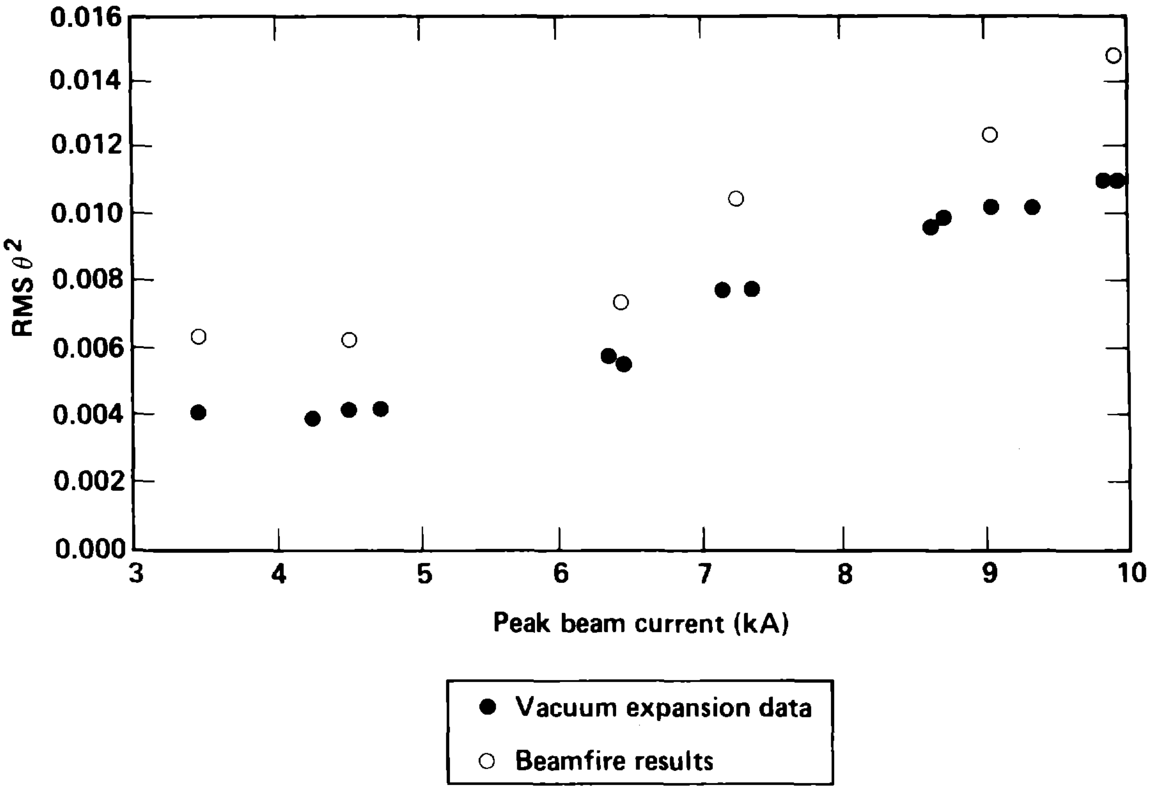

200 mil
carbon foil
5 mm aperature
High pressure
benzene (5 μm)
Low pressure
benzene (0.2 μm)
Laser beam
Experimental
tank

Figure 8



θ^2 is found from fitting the function

$$\frac{I(z)}{I(0)} = 1\text{-exp}\left[\frac{R_p^2}{\theta^2 z^2}\right]$$

To the data or code results

Figure 9